CONTROL OF VORTEX BREAKDOWN BY DENSITY EFFECTS

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The flow inside a cylinder with a rotating end has been recently proposed as a suitable bioreactor for cells growth[1]. Indeed, it creates an efficient laminar mixing which is necessary for the homogeneization of oxygen and nutrients, and for the removal of carbon dioxide. Moreover, the shear created by this flow is much lower than in standard bioreactors which use a magnetic stirrer (rod, barrel or paddle). The properties and control of this flow are thus of critical importance for biological applications.

This flow is well known to lead to a vortex breakdown bubble[2]. Several attempts to control the transition to vortex breakdown have implied the use of a rotating rod[3] or disk[4], but these set-ups were either intrusive or needed a fast rotation speed. Recent numerical results[5] have shown that this flow is extremely sensitive to density differences. The goal of this study is thus to test experimentally this alternative method.

We present experimental results on the control of vortex breakdown inside a cylinder with a rotating top lid. The vortex breakdown is controlled by injecting at the bottom a fluid with a small density difference. The density difference is obtained by mixing a heavy dye or alcohol to water in order to create a jet heavier or lighter than water. The injection of a heavy fluid creates a buoyancy force toward the bottom, which counteracts the recirculation in the cylinder and thus enhances the formation of a vortex breakdown bubble. The stability diagram shows that even a very small density difference of 0.02% is able to decrease by a factor two the critical Reynolds number of appearance of the breakdown. On the other hand, the injection of a light fluid does not destroy the vortex breakdown. However, for large enough density differences (larger than 0.03%), the light fluid is able to pierce through the bubble and leads to a new structure of the vortex breakdown, as shown on figure 1.

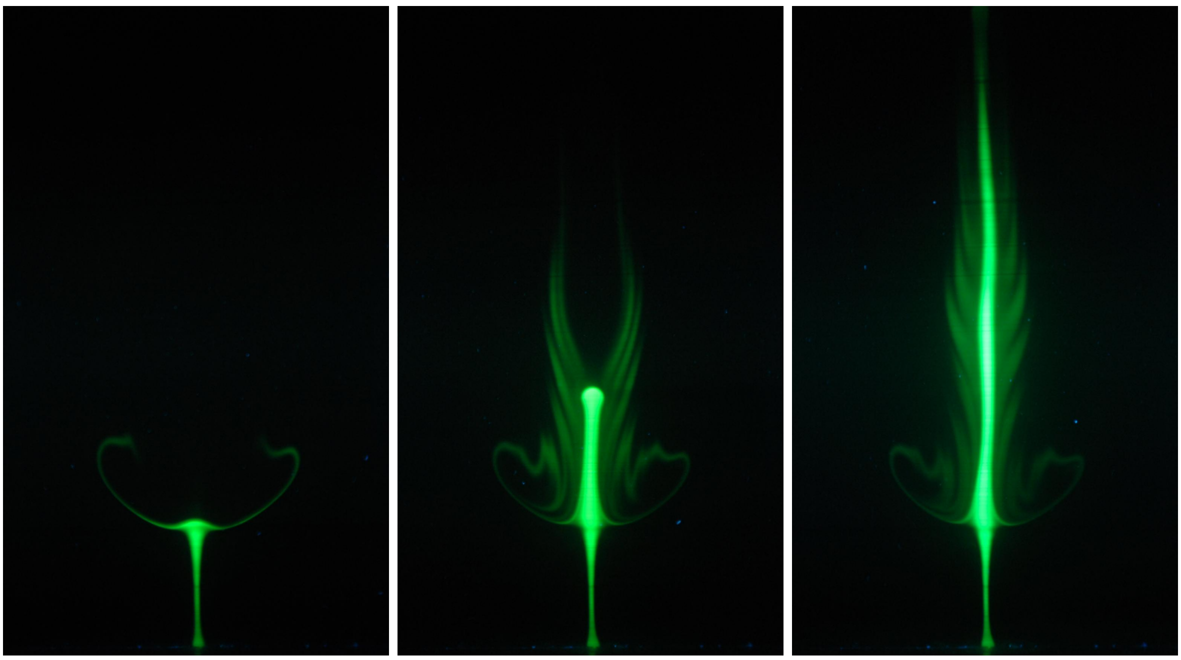

Figure 1: Temporal evolution of a light dye injected below the vortex breakdown and which pierces through the bubble without its destruction. Density difference: $\Delta\rho/\rho_0 = -2.3\ 10^{-4}$. $Re = 2423$.

Figure 2: Temporal evolution of a strong vortex ring impacting the vortex breakdown and piercing through the bubble. $Re = 2000$.

Finally, a parallel is drawn between a light jet and a vortex ring generated at the bottom of the cylinder: strong vortex rings are able to pierce through the bubble, as shown on figure 2, whereas weak vortex rings are simply advected around the bubble.

Additionally, the mixing efficiency of this flow will be briefly mentioned. It has been studied quantitatively by measuring the temporal decay of the variance of the spatial dye distribution. The mixing time, required for homogeneization of the dye, scales on the slow molecular diffusive time for a perfectly axisymmetric flow. However, the presence of a small tilt of the end plates breaks the symmetry and strongly accelerates the mixing. In this case, the mixing time scales on the convective time and can be a few orders of magnitude lower even for small tilt angles.

References

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